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Air Pollution in Moscow Megacity

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1. Introduction

Investigation results of the gas and aerosol air composition over megapolisis are of great interest for the ecology and climate theory. In Moscow statistical regularities can developed from the monitoring data obtained at the Moscow network of automatic stations monitoring air quality (SEI "Mosecomonitoring"). Alternative data are limited essentially.

Monitoring data received in 2003 – 2004 have been analyzed partly in (Gorchakov et al., 2006). Hydrocarbon concentration variations have been studied comprehensively (Gorchakov et al., 2009a). Statistical analysis of the aerosol mass concentration (PM10) variations in 2004 was carried out (Gorchakov et al., 2007). Carbon monoxide and nitrogen oxides concentration profiles in the urban boundary layer according to the data of Ostankino TV Tower measurements during the winter described in (Gorchakov et al., 2009b). Week – long cycle of the air pollution in Moscow was treated in (Gorchakov et al., 2010c). Statistical prediction possibilities of the air pollution in Moscow were analyzed (Gorchakov et al., 2010a, 2010b, 2010c).

Moscow faces a severe atmospheric pollution problem during the smoke haze episodes determined by the forest – peatbog fires (Gorchakov et al., 2003, 2004). Such episodes occurred in July – August 2010. The objective of this chapter is to characterize comprehensively concentration variations of gaseous impurities and aerosol mass concentration (PM10, PM2.5) variations in Moscow. In particular the air pollution in the smoky atmosphere is concerned.

Monitoring system is described in section 2. Temporal variability of the gaseous species of the concentration is discussed in section 3. The results of the statistical analysis are presented in section 4. Aerosol mass concentration variations have been considered in section 5. Section 6 is devoted to the air pollution in the urban boundary layer. The air pollution in the smoky atmosphere is outlined in section 7. Meteorology and the air pollution influence on the health are discussed briefly in section 8. The main results are stated in section 9.

2. Monitoring system

The Air quality monitoring system in Moscow was founded in 1995. The set-up of the air quality monitoring network was designed taking into consideration international experience, such as experience gained by European cities and Directives of the European Union concerning the selection of controlled pollutants, measurement methods, number and location of automatic stations.

Directive 2008/50/EC sets the requirements for number and location of monitoring stations (sampling points), controlled pollutants, measurement techniques, data capture, time coverage and the accuracy of measurements, gathered data and final information on mean concentrations of pollutants.

Regarding the number and location of automatic stations, monitored parameters, monitoring techniques and assets, Air quality monitoring system in Moscow complies with the EU Directives. The measurement techniques are presented in Table 1.

Pollutant	**measurement method used by Mosecomonitoring**
Carbon monoxide	Electro-chemistry, Non-dispersive infrared spectrometry
Nitrogen oxides	Chemiluminescence, DOAS
Sulfur dioxide	Ultraviolet fluorescence method, DOAS
Ozone	Ultraviolet photometry method, Ultraviolet fluorescence method, DOAS
PM10, PM2.5	Beta-guage, TEOM
VOC, Methane	Flame ionization (gas chromatography)
Ammonia	Chemiluminescence
H2S	Ultraviolet fluorescence method
Formaldehyde, Benzene, Toluene, Xylene, Phenol, etc.	DOAS
CO2	Infrared- absorption

Table 1. Measurement techniques.

At present, the Air quality monitoring system includes 37 automatic monitoring stations situated in all administrative districts of the city and covering typical locations of the city in order to represent exposure of general population to different levels and sources of pollution (Fig. 1). Four stations adjoin major motorways, 14 stations are located in residential areas, two stations - in protected nature areas, six stations – in residential areas adjoining industrial enterprises. In addition to this in 2007 two more monitoring stations were set up outside Moscow, at a distance of around 40-50 km from the borders of the city, on the leeward and windward sides judging by the dominant wind direction.

Furthermore, a multilevel monitoring station, which supplies the system with information on air quality at different altitudes (2 m, 130 m, 248 and 348 m above ground), was set up on Moscow TV tower Ostankino in November 2006 (Table 2).

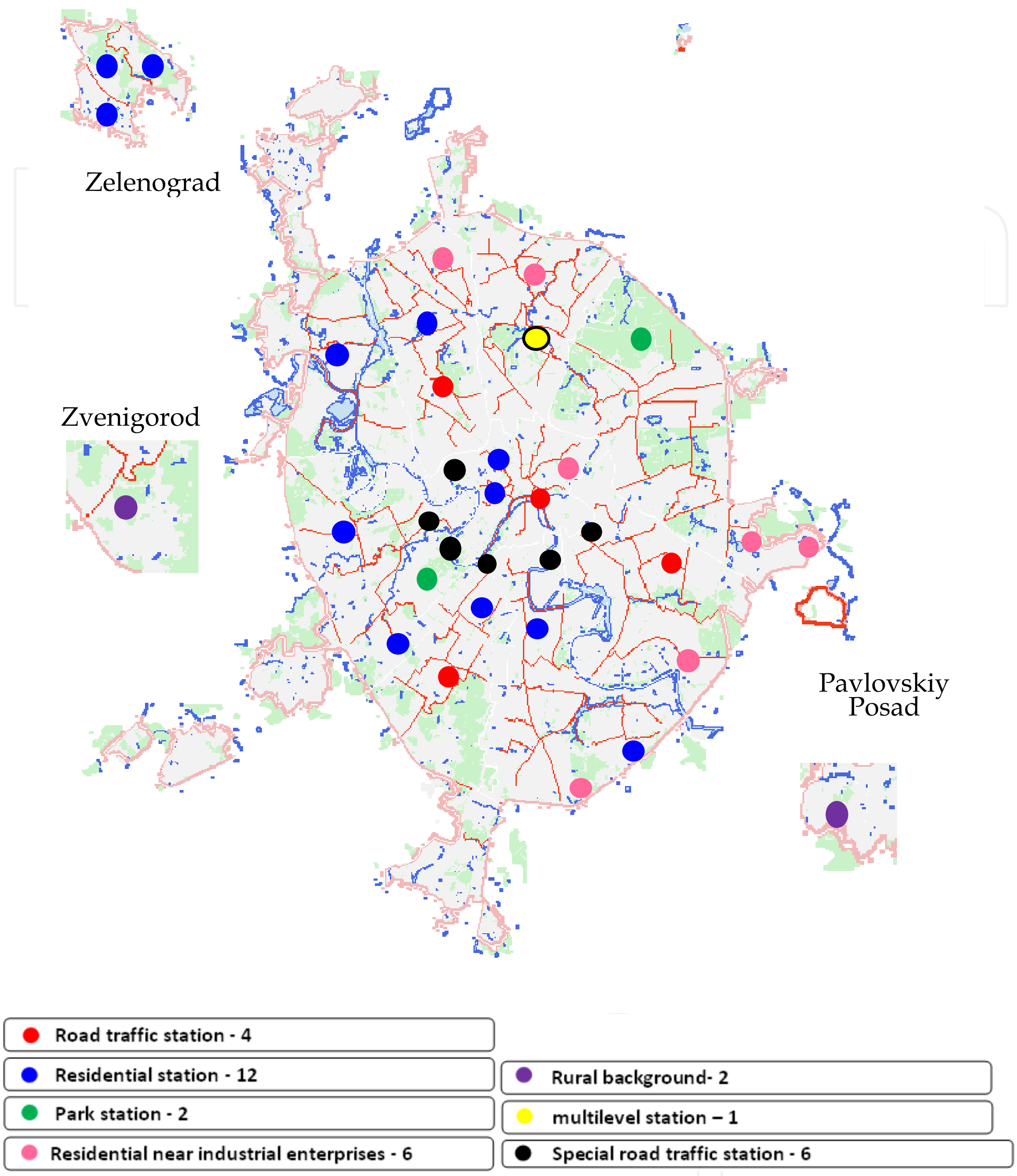

Fig. 1. Location of the automatic stations for the air quality monitoring in Moscow.

Automatic monitoring stations operate twenty-four-hours a day. The complete list of controlled pollutants includes 22 substances, such as CO, NO, NO_2, O_3, SO_2, H_2S, NH_3, CO_2, non – methane hydrocarbons (CH),methane (CH_4), formaldehyde (H_2CO), benzene, toluene, phenol and aerosol (mass concentration PM10 and PM2.5). The list of pollutants, controlled by any particular station, is individual and depends on the type of the territory and emission sources in the area. Still, the concentrations of nitrogen oxides and carbon monoxide are measured by every station. PM10 concentrations are measured at nine stations, ozone concentrations – at 9 and sulfur dioxide – at 10 stations (Table 3).

	Moscow district	Station name	Type of station
1	West	3d Circle ring (Kutuzovskiy pr.)	Special road traffic station
2		3d Circle ring (Kutuzovskiy pr.)	Special road traffic station
3	South West	3d Circle ring (Gagarina sq.)	Special road traffic station
4		3d Circle ring (Hamovnicheskiy Val st.)	Special road traffic station
5	South	3d Circle ring (r. Chura)	Special road traffic station
6	North	3d Circle ring (N. Maslovka st.)	Special road traffic station
7	Central	Balchug (Ovchinnikovskaya nab.)	Road traffic
8		Spiridonovka st.	Residential
9		Chayanova st.	Residential
10		Kazakova st.	Residential (R.) near industrial enterprises
11	South	Gur'evskiy pr.	Residential
12		Shabolovka (Shabolovskaya st.)	Residential
13		Biryulevo	R. near industrial enterprises
14	South East	Veshnyaki (4 Veshnyakovskiy pr.)	Road traffic
15		Marjino (Mar'inskiy park) (Novomarjinskaya st.)	R. near industrial enterprises
16	East	Kosino (Orangerejnaya st.)	R. near industrial enterprises
17		Kozhukhovo (Lukhmanovskaya st.)	R. near industrial enterprises
18		Losiniy Ostrov	Park station
19	North East	Polyarnaya st.	R. near industrial enterprises
20	North	MADI (Leningradsky pr.)	Road traffic
21		Dolgoprudnaya st.	R. near industrial enterprises
22		Koptevskiy bulvar	Residential
23	North West	Turistskaya st.	Residential
24	West	Tolbukhina st.	Residential
25		Vernadskogo pr.	Residential
26		MSU (Moscow State University)	Park station
27	South West	Cheremushki (Cheremushkinskaya st.)	Residential
28		Butlerova st.	Road traffic
29 30 31	Zelenograd (25 km to north west from Moscow)	Zelenograd 11(mikrorajon 11) Zelenograd 6 (mikrorajon 6) Zelenograd 15(mikrorajon 15)	Residential
32	60 km to west from Moscow	Zvenigorod	Rural background
33	60 km to east from Moscow	Pavlovskiy Posad	Rural background
34-37	North East	Ostankino 2m, 130m, 248m, 348m.	Multilevel station

Table 2. Monitoring stations of the SEI Mosecomonitoring

The initial concentration data are averaged over 20- min synchronous intervals, thus allowing a significance decrease in random measurement errors. Then averaged data are automatically introduce into the electronic data base. In accordance with the international standards, the gas analyzers and other instruments are regularly calibrated.

№	Pollutants	Number of stations
1	CO	32
2	NO_2	34
3	NO	28
4	O_3	17
5	PM10	9
6	PM2.5	2
7	SO_2	10
8	NH_3	2
9	H_2S	3
10	Benzene	6
11	Toluene	6
12	Formaldehyde	6
13	Phenol	6
14	Styrene	6
15	Naphthalene	6
16	M-xylene,	6
17	P-xylene,	6
18	Ethyl benzene	6
19	Methane	15
20	Volatile organic compounds VOC)	15
21	VOC without methane	15
22	CO_2	5

Table 3. Pollutants controlled

3. Temporal variability of the gaseous pollutants

Temporal variations of the pollutant concentrations (for example, CO concentration is denoted [CO]) take place over a wide range from minute to years. Some aspects of gaseous species variability are discussed in this section. Fig. 2. gives an idea about the concentration variations of (a) carbon monoxide, (b) nitrogen dioxide, (c) non – methane hydrocarbons, (d) methane, (e) aerosol and (f) ozone. Diurnal variability of the concentration is expressed markedly. The pronounced intradiurnal concentration variations exists. Temporal variations of the concentrations for the variations species and locations diverged considerably. The results presented in this section (Fig. 2) are in an agreement with those obtained previously (Gorchakov et al., 2009a). Some investigation results of the gaseous impurity concentrations presented in (Belikov et al., 2006; Elansky et al., 2007).

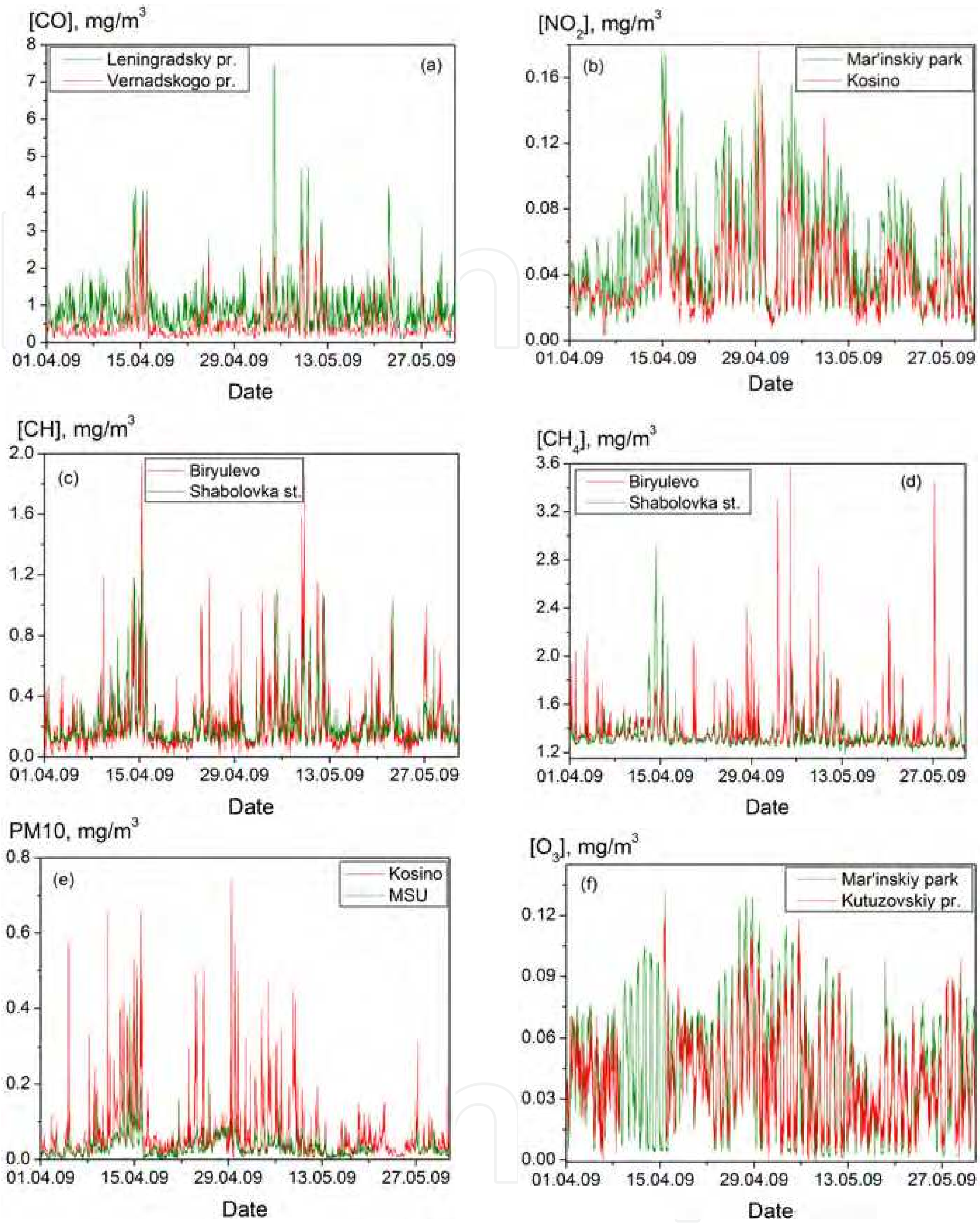

Fig. 2. Concentration variations of (a) carbon monoxide, (b) nitrogen dioxide, (c) non-methane hydrocarbons, (d) methane, (e) aerosol and (f) ozone.

3.1 Diurnal mean cycle of the gaseous species concentrations

Temporal variations of the gaseous species concentrations in 2009 were analyzed. The diurnal mean cycle concentration of carbon monoxide has been shown in Fig. 3 (a – Balchug, b – Kazakova st.). It is evident that the diurnal cycle of the carbon monoxide concentration exhibits the severe seasonal variations. The diurnal mean carbon monoxide various locations are distinguished markedly. Such peculiarities take place for nitrogen dioxide (Fig.

3 c, d), ozone (Fig. 3 e, f) and for other gaseous species. Diurnal concentration variations of carbon monoxide and nitrogen oxides were discussed previously in (Gorchakov et al., 2006). More recently diurnal cycle of non – methane hydrocarbons, methane and toluene was analyzed (Gorchakov et. al., 2009a).

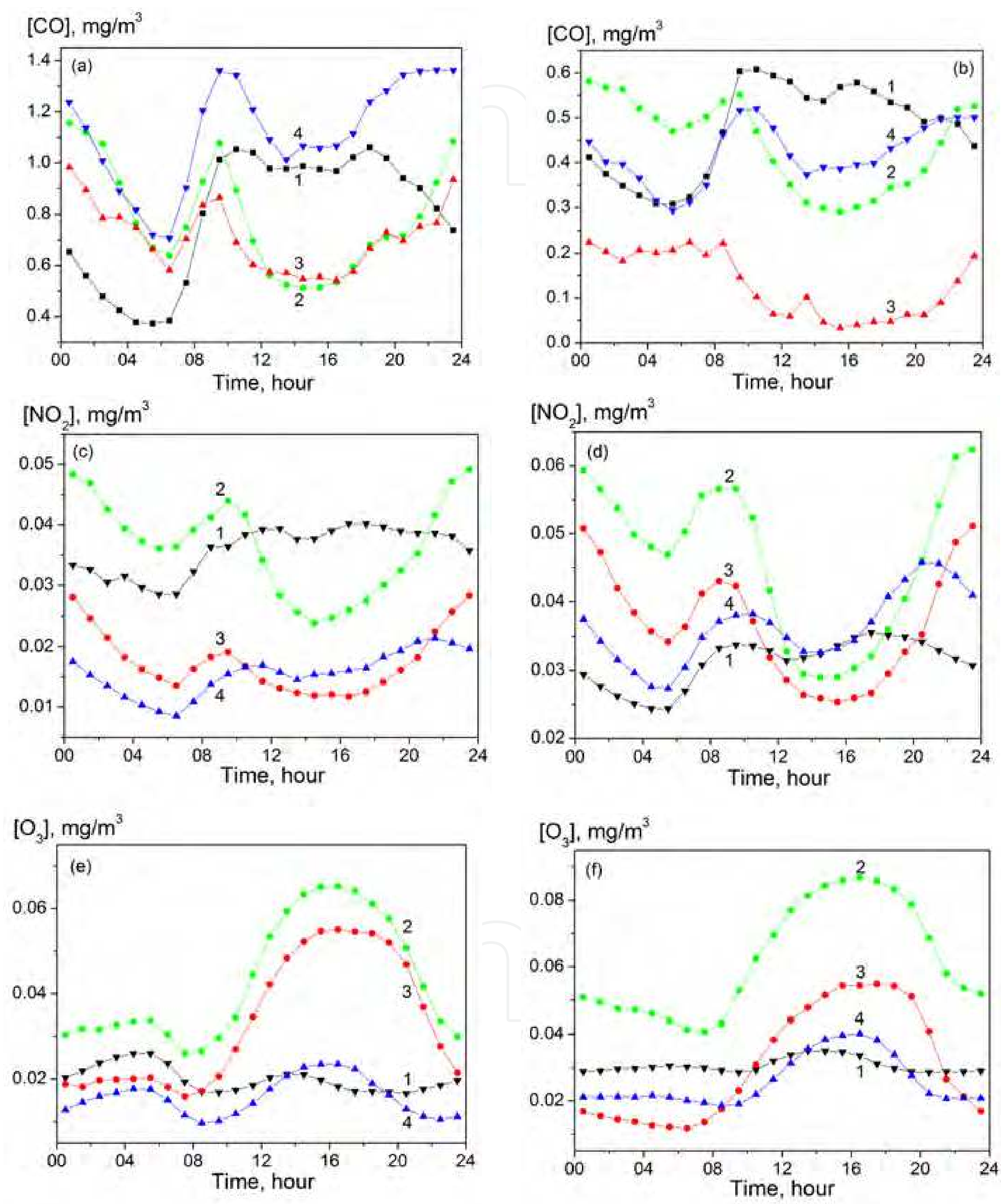

Fig. 3. Diurnal mean cycle (2009) of the carbon monoxide concentration (a – Balchug, b – Kazakova st.), the nitrogen dioxide concentration (c – Balchug, d – Mar'inskiy park) and the ozone concentration (e – Mar'inskiy park, f – Zvenigorod) in (1) winter, (2) spring, (3) summer, and (4) autumn.

As indicated earlier (Gorchakov et al., 2006) the diurnal mean cycle of the carbon monoxide concentration in Moscow changes markedly from the weekdays to the weekends.
Such changes were analyzed on the monitoring data in 2009 (Fig. 4) for (a) carbon monoxide (Balchug), (b) nitrogen dioxide (Mar'inskiy park), (c) ozone (Mar'inskiy park) and hydrogen sulphide (H_2S) (Kosino). Diurnal cycle discussed differ strongly for carbon monoxide, nitrogen dioxide and hydrogen sulphide. The investigation results of the air pollution week – long cycle in Moscow are contained in (Gorchakov et al., 2010) also.

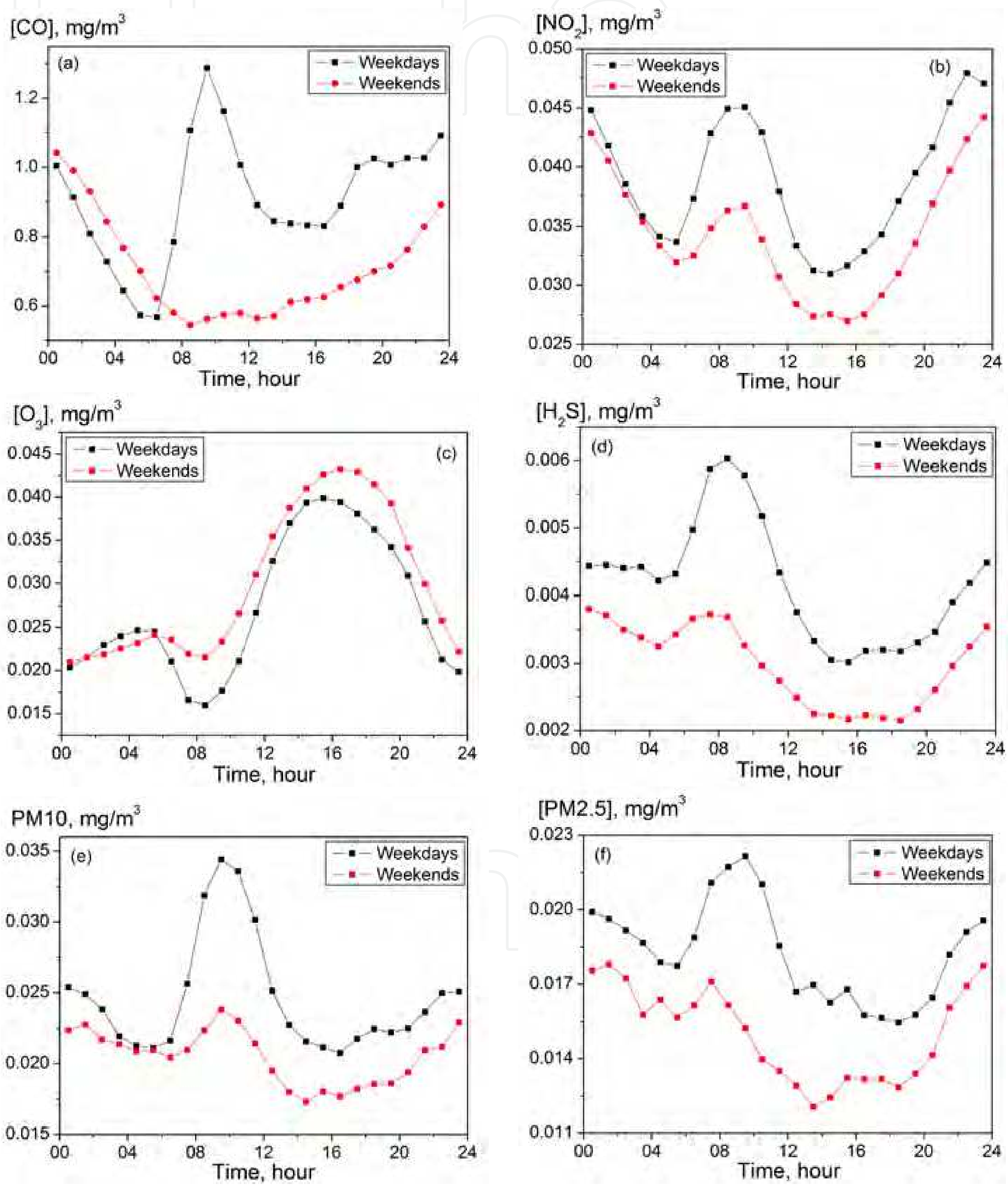

Fig. 4. Diurnal mean concentration cycles (2009) of (a) carbon monoxide (Balchug), (b) nitrogen dioxide (Mar'inskiy park), (c) ozone (Mar'inskiy park), (d) H_2S (Kosino), (e) PM10 (Shabolovka) and (f) PM2.5 (Kosino) at weekdays and at weekends.

3.2 Intraannual variability of the gaseous species concentrations

Intraannual cycles of the gaseous species concentrations (Fig. 5) are of great variety (MSU – Moscow State University). They change from one another for the various species and locations including carbon monoxide (Fig. 5a), nitrogen dioxide (Fig. 5b), non – methane hydrocarbons (Fig. 5c), methane (Fig. 5d) and ozone (Fig. 5f). Intraannual and seasonal concentration variability's for carbon monoxide, non-methane benzene, toluene, metaxylene and formaldehyde has been discussed in (Gorchakov et al., 2009a). Enhanced concentrations

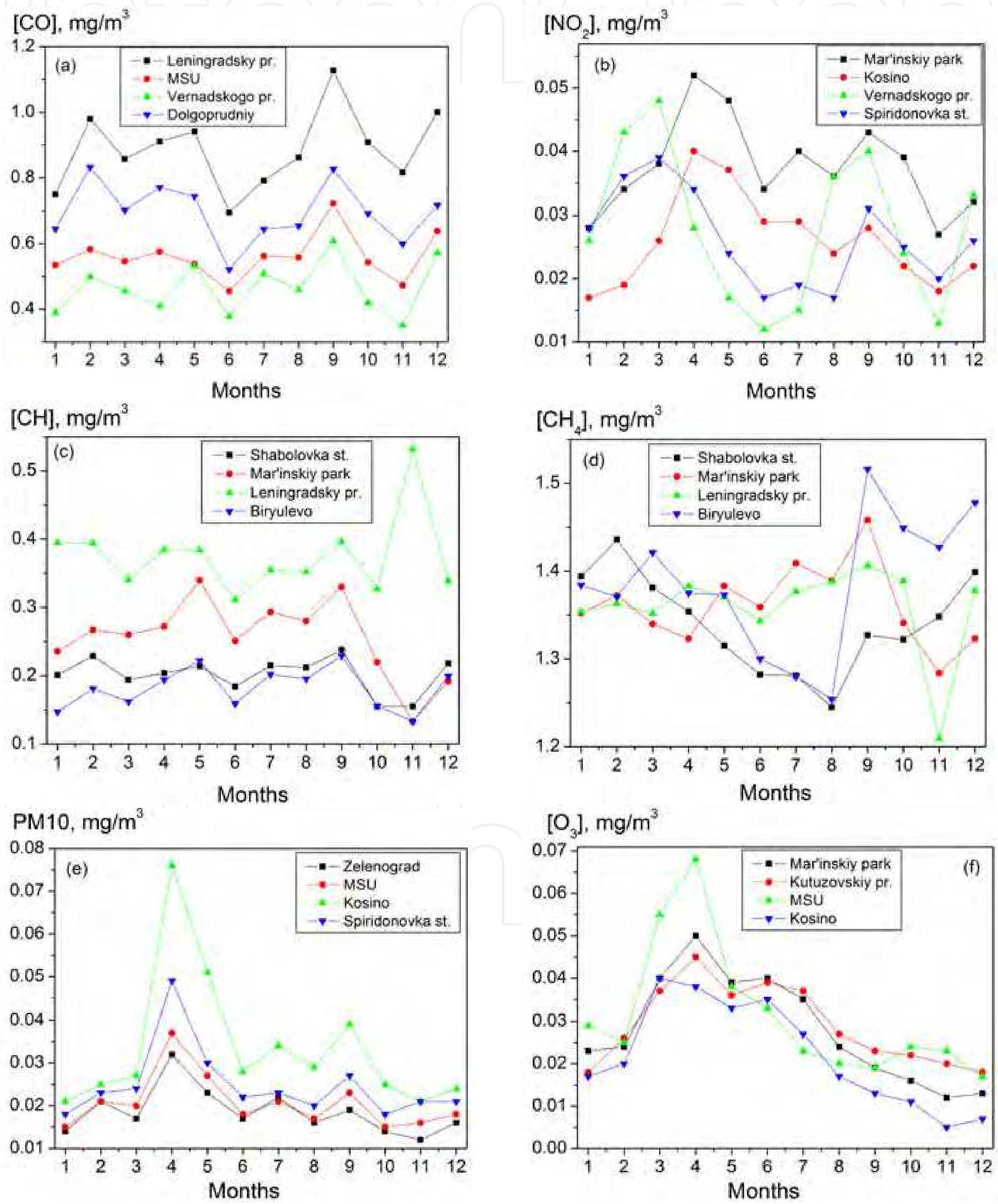

Fig. 5. Monthly average concentration (Moscow, 2009) of (a) carbon monoxide, (b) nitrogen dioxide, (c) non-methane hydrocarbons, (d) methane, (e) PM10 and (f) ozone.

of the gaseous species are observed under adverse weather conditions or smoke invasions during the forest and peatbog fires (section 7).

3.3 Interannual variability of the gaseous species concentrations

In Moscow the gaseous species interannual concentration experience a large variations. As an example we discuss the annual average concentration of the carbon monoxide (Table 4). There are many irregular variations of the carbon monoxide concentrations. It is evident (Table 4) that the average (for station group) concentration of carbon monoxide in 2002 – 2003 was approximately 2.5 times greater than the average concentration in 2008 – 2009.

Station	Year							
	2002	2003	2004	2005	2006	2007	2008	2009
Leningradsky pr.	2.2	2.5	2.4	2.2	1.5	1.3	0.9	0.9
Biryulevo	1.6	1.1	1.4	1.5	1.5	1.3	0.6	0.8
Balchug	1.5	1.7	1.2	1.1	1.0	0.8	0.8	0.9
Mar'inskiy park	1.6	2.1	1.0	0.8	0.7	0.8	0.5	0.5
Kazakova st.	2.0	1.8	1.2	1.6	1.5	0.9	0.5	0.4
Shabolovka st.	1.3	-	0.9	0.8	0.7	0.5	0.4	0.6
Kosino	-	0.7	1.6	0.7	0.8	0.9	0.6	0.5
Losiniy ostrov	-	0.7	0.6	0.6	0.4	0.4	0.4	0.4

Table 4. Annual average concentrations of carbon monoxide (mg/m^3).

3.4 Spectral analysis of the gaseous species concentration variations

The power spectral densities (Bendat & Piersol, 1986) of the gaseous species concentration variations were calculated for a number of stations. As an example, Fig. 6 shows the power spectral density of the nitrogen dioxide concentration variations calculated from the 2004 data obtained at Vernadskogo pr. It is easily seen that the spectral density $S(f)$ (1 in Fig. 7), where f is the frequency in inverse days, contains two components: continuous and quasi – discrete.

The continuous component is satisfactory approximated by a piecewise power spectrum

$$S_*(f) = Af^k ,$$

where $A = const$ and k – exponent. Irregular diurnal variations in $[NO_2]$ with a periods of less than 24 h are approximated by the power spectrum (2 in Fig. 7) with the exponent – 2 approximately . It should be noted that there are no grounds to assign this power spectrum to universal spectrum. It was found that, for different stations and different years, the spectrum's exponent varies within a sufficiently wide range, a result which cannot be explained by measurement errors. The day-to-day variations of $[NO_2]$ are also approximated by a power spectrum (3 in Fig. 7). In the case under consideration, the exponent of the second approximating spectrum is approximately – 0.55. This spectrum cannot to universal spectra either. This exponent of spectrum varies within a comparatively wide range from station to station and from year to year. The approximating power spectra are joined together near the frequency $f_0 \cong 1$ day. The quasi – discrete component of the spectrum $S_{**}[NO_2]$ (4, 5 and 6 in Fig. 7) is due to the existence of a regular diurnal cycle containing harmonies with periods of 24, 12 and 8 h. The structure of the spectrum also varies markedly from station to station, this testifying to the spatial variability of the diurnal cycle of $[NO_2]$.

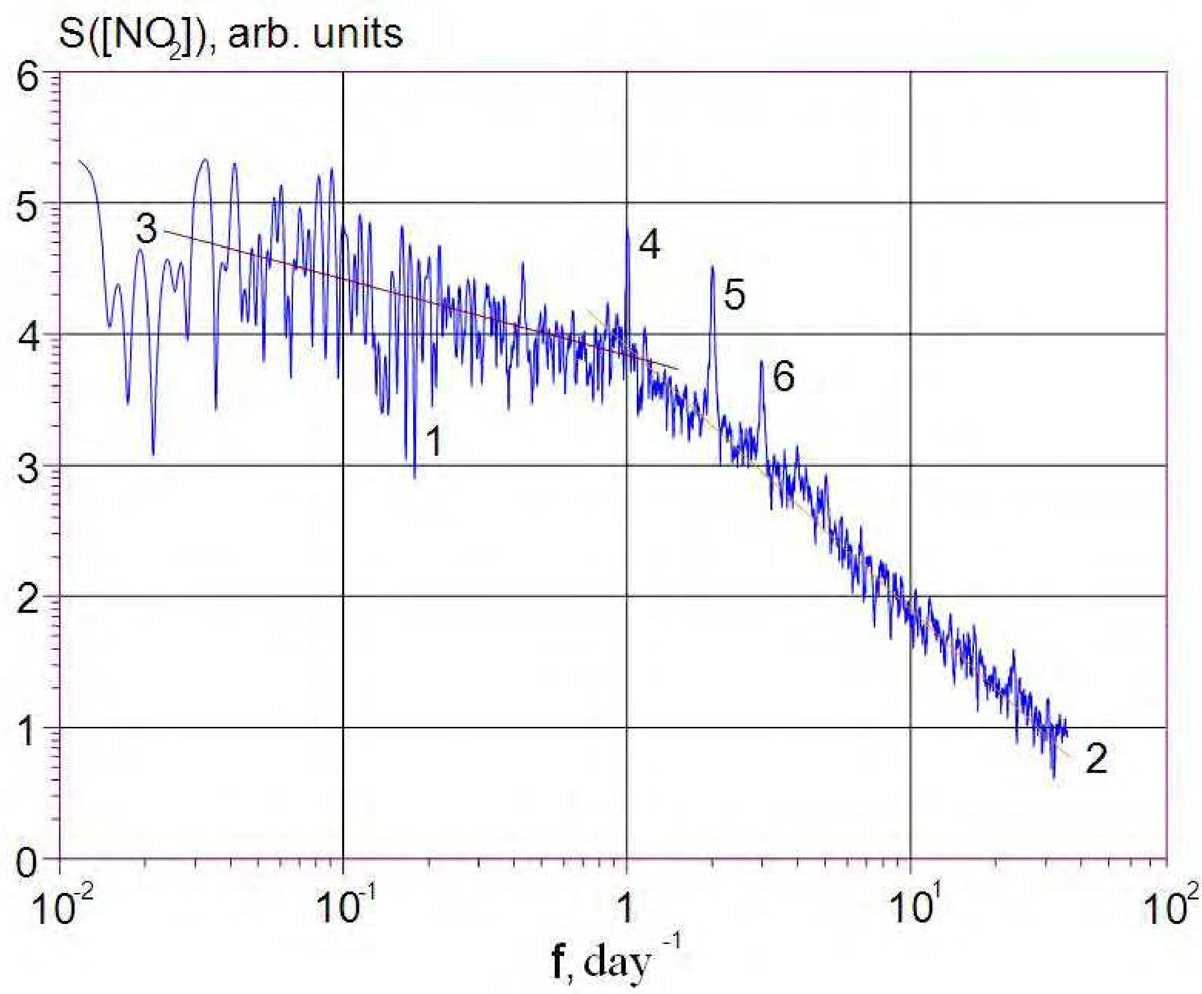

Fig. 6. Spectral power of the nitrogen dioxide concentration variations on the measurement data at Vernadskogo pr. in 2004 (2 and 3 – exponential approximating spectra; 4, 5 and 6 – harmonics with period 24, 12 and 8 hour).

4. Statistical analysis of the gaseous species concentration variations

The average values of the concentrations $\bar{C}_i = n_i^{-1}\sum_k C_{ik}$ (i is the pollutant number, k is the measurement number, and n_i is the number of measurements of the it h pollutant) were determined for the various time intervals. The basic statistical characteristics of concentration variations were calculated: the standard deviations σ_i and the dispersions $\sigma_i^2 = (n_i - 1)^{-1}\sum_k c_{ik}^2$ (for large series, it is convenient to replace n_i -1 by n_i), where

$c_{ik} = C_{ik} - \bar{C}$ - the deviations from average values; the variation coefficients $\gamma_i = \sigma_i / \bar{C}_i$, the skewness parameters $A_i = n_i^{-1} \sum_k c_{ik}^3$, and the excess parameters $E_i = -3 + n_i^{-1} \sigma_i^{-4} \sum_k c_{ik}^4$. In section 4, statistical characteristics of concentration variations were calculated from the monitoring data during 2009.

4.1 Carbon monoxide

Statistical characteristics of the carbon monoxide concentration variations for 8 station presented in Table 5. It is evident that average concentrations in Moscow is 2 – 3 times greater than outside the Moscow city (Pavlovskiy Posad, Losiniy ostrov, Zvenigorod). Carbon monoxide concentrations in 2004 in the average were approximately 2-times larger than the concentrations in 2009 (Gorchakov et al., 2006). As to the variation coefficients γ_i, they were approximately the same. An example of the empirical distribution function w [CO] (Narodnogo Opolcheniya st., 2004) is Fig. 7. This function is satisfactory approximated by log – normal distribution

$$p(x) = \frac{B_1}{\sigma_* \sqrt{2\pi}} \exp\left\{ -\frac{(x - x_0)^2}{2\sigma_*^2} \right\},$$

where $x = \ln([CO])$, $x_0 = 0.4$, $\sigma_* = 0.035$ and $B_1 = 18.5$. The empirical distribution

Station	$\bar{C}$	σ	γ	A	E
	mg/m³				
Balchug	0.86	0.82	0.96	3.72	22.6
Leningradsky pr.	0.89	0.55	0.62	1.98	8.9
Biryulevo	0.78	0.72	0.92	3.60	19.9
Cheremushki	0.55	0.64	1.17	5.26	39.6
Chayanova st.	0.53	0.44	0.83	3.07	16.2
Pavlovskiy Posad	0.40	0.29	0.72	2.64	14.3
Losiniy Ostrov	0.37	0.29	0.78	3.34	23.5
Zvenigorod	0.28	0.26	0.92	1.78	8.7

Table 5. Statistical characteristics of the carbon monoxide (CO) concentration in 2009.

function w calculated on monitoring data in 2009 is shown in Fig. 8a with the distribution function for the smoke episode (section 7).

4.2 Nitrogen oxides

Statistical characteristics calculation results for nitrogen oxide and nitrogen dioxide are depicted in Table 6 and Table 7. Average annual concentrations of nitrogen oxides in 2009 are 1.5 – 2 times smaller than average concentrations in 2004 (Gorchakov et al., 2006). The empirical distribution function w of the nitrogen dioxide concentration is presented in Fig. 9 (Narodnogo Opolcheniya st., 2004). This distribution function is satisfactory approximated by log – normal distribution

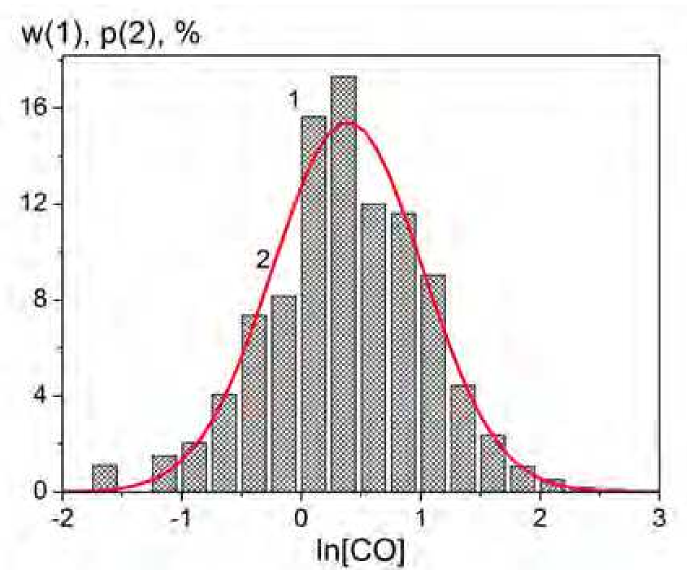

Fig. 7. The empirical distribution function w(1) of the carbon monoxide concentration in 2004 (Narodnogo Opolcheniya st.) and the log-normal approximated distribution p(2).

$$p(y) = \frac{B_2}{\sigma_{**}\sqrt{2\pi}} \exp\left\{-\frac{(y-y_0)^2}{2\sigma_*^2}\right\},$$

where $y = \ln([NO_2])$, $y_0 = -3.7$, $\sigma_{**} = 0.79$ and $C = 31.5$.

Additional examples of the empiric distribution function and NO_2 (2009) are presented in Fig. 8b. Temporal variations of the NO_2 concentration are illustrated in Fig. 3c, Fig. 3d, Fig. 4b and Fig. 5b.

4.3 Ozone

Ozone plays the important role in the atmospheric chemistry (Belan, 2009). The ozone importance in the ultraviolet and infrared radiation transfer is significant. The large ozone concentrations are a potential health hazard. Temporal variations of the ozone concentration is shown in Fig. 2f, the diurnal mean cycle of concentration – in Fig. 3e, Fig. 3f and Fig. 4c. Examples of the monthly average ozone concentration are presented in Fig. 5f.

Statistical characteristics of the ozone concentration variation at 5 stations (Moscow region, 2009) are presented in Table 8. The empirical distribution function of the ozone concentration is depicted in Fig. 8f.

Station	$\bar{C}$ (mg/m³)	σ (mg/m³)	γ	A	E
Cheremushki	0.029	0.055	1.92	5.78	45.0
Kazakova st.	0.030	0.051	1.68	3.78	37.6
Balchug	0.035	0.043	1.22	4.48	31.3
Kozhuhovo	0.020	0.034	1.72	3.95	20.4
Veshnyaki	0.043	0.082	1.92	4.61	30.0
Leningradsky pr.	0.067	0.057	0.85	2.68	13.2

Table 6. Statistical characteristics of the nitrogen oxide (NO) concentration in 2009.

Station	$\bar{C}$ (mg/m³)	σ (mg/m³)	γ	**A**	E
Kutuzovskiy pr.	0.044	0.022	0.50	1.20	2.80
Cheremushki	0.038	0.028	0.75	1.67	5.83
Kazakova st.	0.032	0.022	0.70	1.22	2.56
Balchug	0.026	0.021	0.80	2.30	19.9
Kozhuhovo	0.021	0.016	0.71	1.19	1.74

Table 7. Statistical characteristics of the nitrogen dioxide (NO_2) in 2009.

Station	$\bar{C}$ (mg/m³)	σ (mg/m³)	γ	**A**	E
Zvenigorod	0.038	0.029	0.76	0.72	0.33
Zelenograd	0.038	0.028	0.75	0.72	0.11
Gagarina sq.	0.033	0.022	0.68	0.81	0.35
Mar'inskiy park	0.028	0.023	0.84	0.99	0.48
Hamovniki	0.023	0.018	0.76	1.31	1.23

Table 8. Statistical characteristics of the ozone (O_3) concentration in 2009.

Station	$\bar{C}$ (mg/m³)	σ (mg/m³)	γ	**A**	E
Leningradsky pr.	0.38	0.17	0.45	2.37	11.1
Balchug	0.27	0.15	0.55	3.22	20.5
Pavlovskiy Posad	0.21	0.12	0.56	4.78	48.8
Cheremushki	0.17	0.16	0.93	3.68	18.2
Ostankino	0.16	0.11	0.67	2.95	14.7

Table 9. Statistical characteristics of the hydrocarbon concentration in 2009.

In the average the ozone concentrations is Moscow are markedly less than outside of city. Temporal variations of the ozone concentration in the Moscow region need further concentration.

4.4 Methane and non-methane hydrocarbons

In 2009 the average non-methane hydrocarbon concentration (Table 9) in Moscow were 20 – 30% higher than that in 2004 (Gorchakov et al., 2009 a). Variation coefficients γ of the non - methane concentration variations in 2009 were markedly less than that in 2004. Temporal variations of the non-methane hydrocarbon concentration are depicted in Fig. 2c and Fig. 5c, and temporal variations of the methane concentration – in Fig. 2d and Fig. 5d. It is hard to evaluate the interannual variability of the methane concentration now (Table 10). In the average the statistical parameters A and E in 2009 are markedly larger than that in 2004 (Corchakov et al., 2009 a).

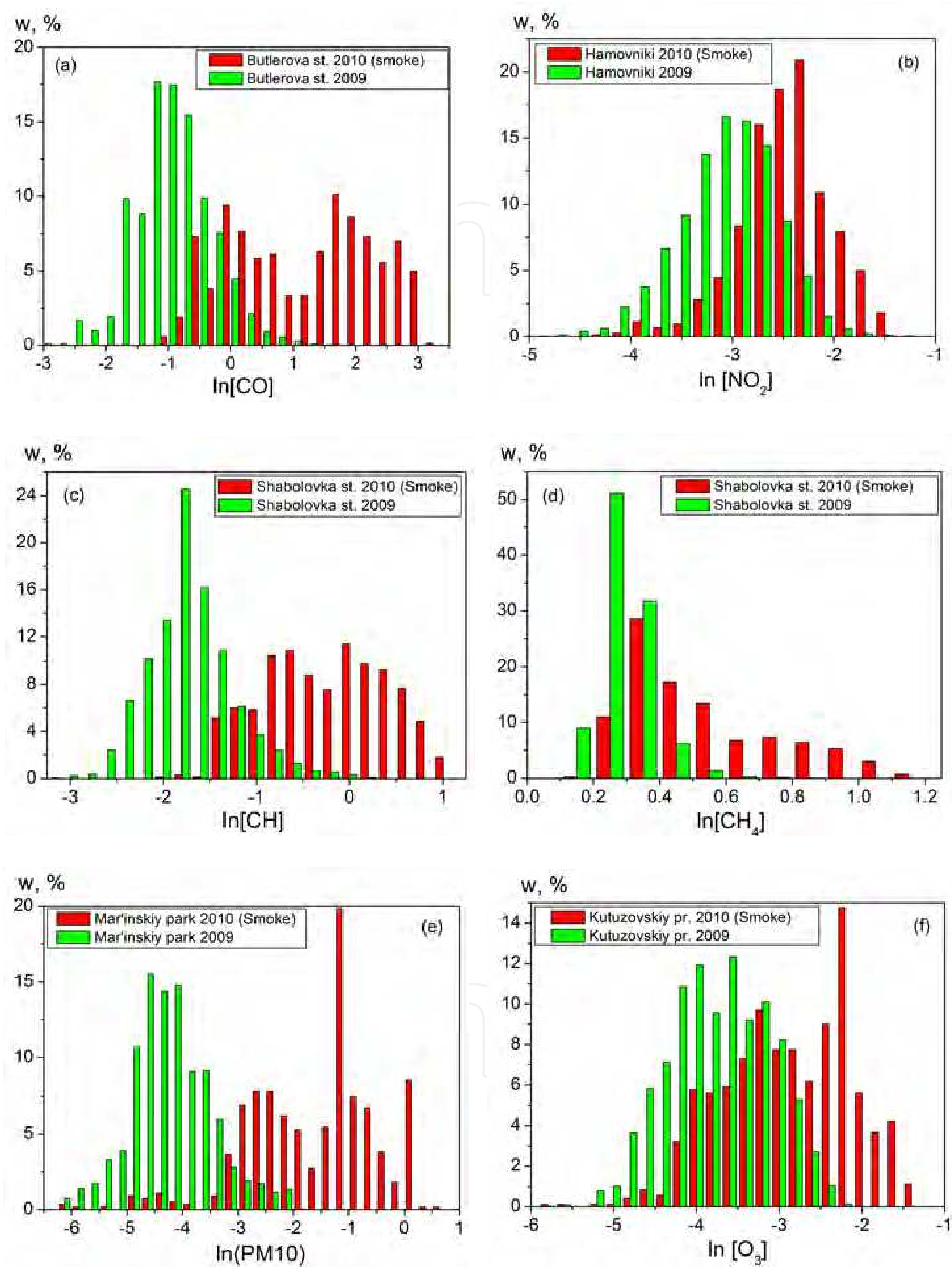

Fig. 8. Empirical distribution function for the concentrations (Moscow, 2009 – green; Moscow 2010, smoke episode – red) of (a) carbon monoxide, (b) nitrogen dioxide, (c) non-methane hydrocarbons, (d) methane, (e) PM10 and (f) ozone.

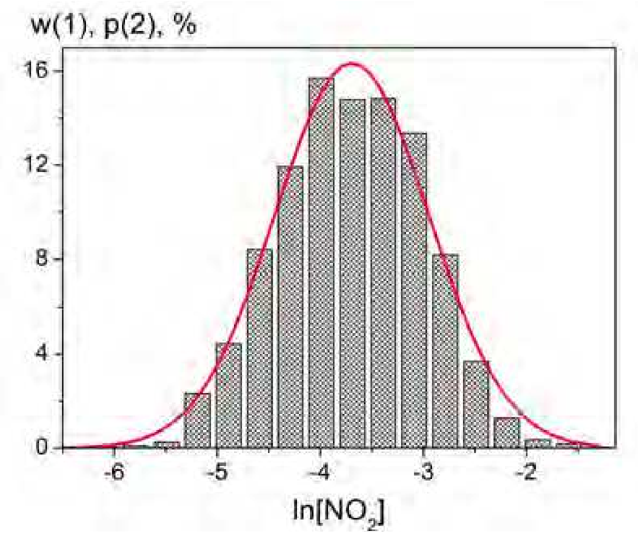

Fig. 9. The empirical distribution function w(1) of the nitrogen dioxide concentration in 2004 (Narodnogo Opolcheniya st.) and the log-normal approximating distribution p(2).

Station	$\bar{C}$	σ	γ	A	E
	mg/m^3				
Cheremushki	1.45	0.11	0.078	2.76	35.6
Biryulevo	1.39	0.19	0.73	5.00	58.5
Mar'inskiy park	1.36	0.16	0.12	5.21	40.5
Vernadskogo pr.	1.27	0.25	0.19	7.19	79.3
Ostankino	1.26	0.095	0.076	1.85	9.30

Table 10. Statistical characteristics of the methane (CH_4) in 2009

5. Aerosol mass concentration

Aerosol mass concentration PM10 is measured at 9 stations and PM2.5 – at 2 stations at present. Temporal variability of PM10 is illustrated in Fig 2e. Examples of diurnal cycle of PM10 and PM2.5 at weekdays and weekends are depicted in Fig. 4e and 4f. It is evident that an anthropogenic influence on aerosol mass concentrations in Moscow is large. Intraannual variability of PM10 is illustrated in Fig. 5e. Statistical characteristics of PM10 variations are of PM10 variations are presented in Table 11 (Moscow, 2009). In the average PM10 concentrations in 2009 are markedly less than that in 2004 (Gorchakov et al., 2007) and variation coefficients in 2004 are larger than that in 2009. Example of the empirical distribution on function for PM10 is presented in Fig. 8e. The additional data about PM10 variations in Moscow can find in (Gorchakov et al., 2007).

6. Air pollution in the urban boundary layer

The modern strategy of environmental protection in urbanized territories stimulates the need for data from the monitoring of some pollutant components in the surface atmospheric air for the solutions to problems of the diagnosis and prediction of atmospheric air

Station	$\bar{C}$	σ	γ	A	E
	mg/m³				
Pavlovskiy Posad	0.029	0.030	1.02	5.36	59.3
Ostankino	0.027	0.024	0.87	4.55	41.4
Kozhuhovo	0.026	0.022	0.87	3.19	16.9
Shabolovka st.	0.023	0.020	0.83	4.25	31.9
Zelenograd	0.019	0.015	0.80	2.63	12.4

Table 11. Statistical characteristics of the PM10 in 2009.

pollution. However, the solution of problems of the spread and transformation of gas and aerosol pollutant components of the air basins of big cities presents serious difficulties associated with the lack of information on the meteorological processes in the atmospheric boundary layer over a city, including the formation of low level jet streams; the mechanisms of admixture transport by vertical structures, e.g., in street canyons; the role of the convective process; and the structure of a "multimodal heat island" over a city genetically related with the "pollution cap" and complex air circulation over a city. Hence there is a need for additional experimental studies of the meteorological processes and regularities of the vertical distribution of gas and aerosol admixtures in the urban boundary layer. Therefore, to identify the statistical regularities of pollutant concentration variations in the atmospheric boundary layer, the knowledge of which is necessary in order to create adequate pollutant spread models and to assess the ecologic state under conditions of dense and especially multistorey buildings, these data are clearly insufficient. Therefore, since November 2006 in Moscow, in the framework of an urban system of atmospheric air pollution control, the monitoring of the vertical distributions of certain gas components of atmospheric air pollution from the Ostankino TV Tower has been performed. The monitoring of the vertical profiles of gas components of atmospheric air pollution over the city together with the monitoring of gas and aerosol components at 35 sites in Moscow and two sites outside of the Moscow megapolis provide invaluable information on the complex processes of pollutant transport and transformation in the air basin of a big megapolis.

In this chapter are analyzed the monitoring data of the carbon monoxide and nitrogen dioxide concentrations on 4 levels of the Osnankino TV tower.

Statistical characteristics of the carbon monoxide concentration variations in 2009 (Table 12) are consistent with results presented in (Gorchakov et. al., 2009 b). Vertical profile of the nitrogen dioxide concentration variations are of interest. In the average maximal concentration of nitrogen dioxide is observed at height 130 m (Table 13) and minimal concentration – at height 348 m.

Height, m	$\bar{C}$	σ	γ	A	E
	mg/m³				
2	0.56	0.46	0.82	3.28	17.1
130	0.39	0.29	0.74	2.76	16.7
248	0.40	0.31	0.76	2.64	17.0
348	0.37	0.46	1.23	4.76	40.1

Table 12. Statistical characteristics of the carbon monoxide (CO) concentration (Ostankino, 2009).

Height, м	$\bar{C}$	σ	γ	A	E
	mg/m³				
2	0.027	0.014	0.54	1.01	1.50
130	0.043	0.025	0.58	2.05	7.22
248	0.025	0.023	0.92	1.70	4.14
348	0.016	0.013	0.81	1.60	4.65

Table 13. Statistical characteristics of the nitrogen dioxide (NO_2) concentration (Ostankino, 2009).

7. Air pollution in the smoky atmosphere

The biomass burning represents a powerful source of the specific aerosol. Large-scale forest, peatbog and steppe fires have long been the subject of geophysical studies, because smoke formation leads to a radical change in the atmospheric radiative regime and, consequently, is capable of causing noticeable regional climatic effects. Characteristic examples of burning of large biomass amounts are the peatbog fires that happened in 1972 and 2002 in central Russia. The extent of the smoke screening of Moscow region in summer 2010 was exceed preceding events (Gorchakov et al., 2011).

7.1 Surface layer contamination

The carbon monoxide concentrations in Moscow during the forest – peat bog fires in the summer season of 2010 reached an extreme large values (Fig. 10). Statistical characteristics of the carbon monoxide concentration variations at 7 stations and maximal concentrations (C_{max}) for during period from 1 August to 11 August are given in Table 14. In this time average concentration of carbon monoxide were 3 – 5 times greater than the annual average concentrations.

Station	$\bar{C}$	σ	C_{max}	γ	A	E
	mg/m³					
Balchug	7.24	7.34	37.4	1.01	1.48	1.68
Cheremushki	6.84	7.48	33.7	1.09	1.29	0.72
Butlerova st.	5.03	4.88	20.2	0.97	1.13	0.28
Dolgoprudnaya st.	5.02	4.72	23.8	0.94	1.24	1.00
Vernadskogo pr.	4.75	4.57	18.0	0.96	1.13	0.24
Pavlovskiy Posad	4.13	4.15	19.5	1.01	1.52	2.09
Zvenigorod	3.14	3.34	15.4	1.07	1.38	1.22

Table 14. Statistical characteristics of the carbon monoxide (CO) concentration (2010, smoke).

The maximal concentration of carbon monoxide in 2010 was 2.5 times larger than that in 2002 (Gorchakov et al., 2003, 2004). Statistical parameters A and E for the smoky atmosphere were markedly less then that in 2009. The empirical distribution function of [CO] are depicted in Fig. 8a (smoke screening period).

Exceeding probabilities of the some threshold concentration for carbon monoxide in the smoky atmosphere were calculated (Table 15). In 2004 exceeding the level of 15 mg/m³ are not observed (Gorchakov et al., 2006). Average concentrations of nitrogen dioxide (Table 16) in the smoky atmosphere were approximately 2 – 3 times great as before (in 2009).

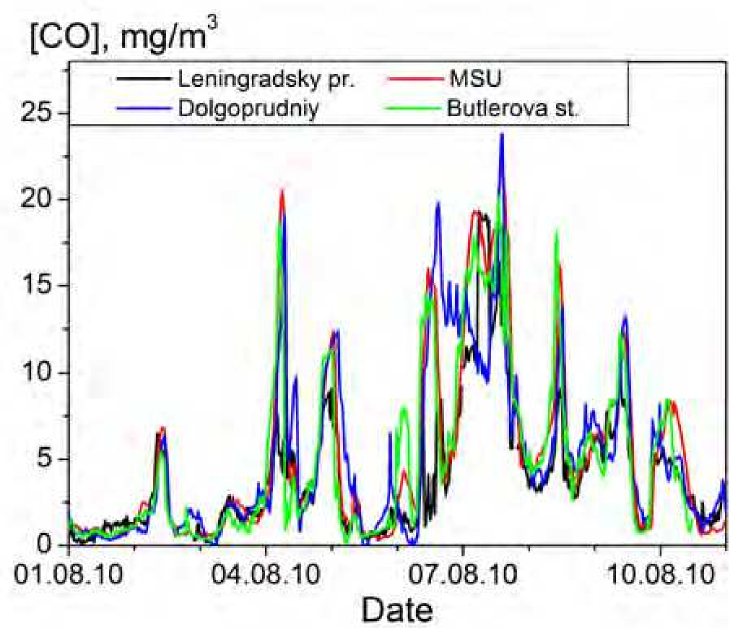

Fig. 10. Temporal variations of the carbon monoxide concentration in the smoky atmosphere.

Ozone concentrations in the Moscow city during the period under review were 1.5 – 2 times greater than the topical concentrations, as a rule (Table 17). Statistical parameters γ, A and E for ozone in the smoky atmosphere differ little from the statistical parameters for ozone in 2009. The empirical distribution functions of $[NO_2]$ and $[O_3]$ are presented in Fig. 8b and Fig. 8f (smoke screening period).

Station	Threshold concentrations						
	5	10	15	20	25	30	35
Balchug	49.2	24.3	15.3	8.5	3.9	1.25	0.14
Cheremushki	44.7	26.6	17.2	9.4	2.8	0.70	-
Gur'evskiy pr.	38.2	9.8	4.0	1.7	0.70	-	-
Biryulevo	29.5	10.2	5.3	1.0	-	-	-
Kazakova st.	25.8	8.3	2.3	1.1	-	-	-
Shabolovka	27.3	12.7	2.0	-	-	-	-

Table 15. Exceeding probabilities (%) of the threshold concentrations (mg/m³) for carbon monoxide in the smoke screening period.

Statistical characteristics of the concentration variations of non - methane hydrocarbons and methane are presented in Table 18 and Table 19.

The average methane concentration in the smoky atmosphere exceed insignificantly average concentrations in 2009. The empirical distribution function of [CH] and [CH_4] are shown in Fig. 8c and Fig. 8d.

Station	$\bar{C}$ (mg/m^3)	σ (mg/m^3)	γ	A	E
Biryulevo	0.126	0.058	0.46	0.46	- 0.42
Hamovniki	0.094	0.040	0.43	0.90	0.92
Tolbuhina st.	0.073	0.058	0.80	1.36	1.92
MSU	0.068	0.025	0.37	1.88	7.31
Zelenograd	0.058	0.040	0.69	1.10	0.58
Pavlovskiy Posad	0.044	0.026	0.60	1.04	1.12
Cheremushki	0.038	0.021	0.56	0.99	0.93
Zvenigorod	0.032	0.022	0.70	1.17	1.64

Table 16. Statistical characteristics of the nitrogen dioxide (NO_2) concentration (2010, smoke)

Station	$\bar{C}$ (mg/m^3)	σ (mg/m^3)	γ	**A**	E
Kutuzovsky pr.	0.074	0.052	0.70	1.02	0.50
Maslovka	0.063	0.035	0.55	1.20	1.35
Spiridonovka st.	0.049	0.052	1.07	0.96	- 0.04
Mar'inskiy park.	0.045	0.048	1.07	1.31	1.69
Pavlovskiy Posad	0.045	0.036	0.79	0.63	- 0.94

Table 17. Statistical characteristics of the ozone concentration (2010, smoke)

Station	$\bar{C}$ (mg/m^3)	σ (mg/m^3)	γ	**A**	E
Golovacheva st.	1.10	0.73	0.66	1.39	1.88
Tolbukhina st.	1.07	0.73	0.69	0.68	- 0.74
Vernadskogo pr.	0.99	0.60	0.60	1.46	3.90
Cheremushki	0.94	0.72	0.77	1.15	0.79
Mar'inskiy park	0.71	0.78	1.09	1.24	0.70
Biryulevo	0.69	0.56	0.80	1.57	2.23
Zelenograd	0.57	0.41	0.71	0.88	0.02

Table 18. Statistical characteristics of non-methane hydrocarbon concentration (2010, smoke)

Station	$\bar{C}$	σ	γ	A	E
	mg/m³				
Golovacheva st.	1.94	0.69	0.36	1.31	0.84
Cheremushki	1.78	0.42	0.23	1.42	1.58
Biryulevo	1.66	0.45	0.27	2.24	5.81
Zelenograd	1.41	0.26	0.19	1.11	0.53
Tolbukhina st.	1.37	0.31	0.23	1.16	2.62

Table 19. Statistical characteristics of the methane (CH_4) concentrations (2010, smoke)

Temporal variations of the formaldehyde concentrations in the smoky atmosphere are shown in Fig. 11. Statistical characteristics of the formaldehyde concentration variations in 2009 and in the smoky atmosphere (2010) are presented in Table 20.

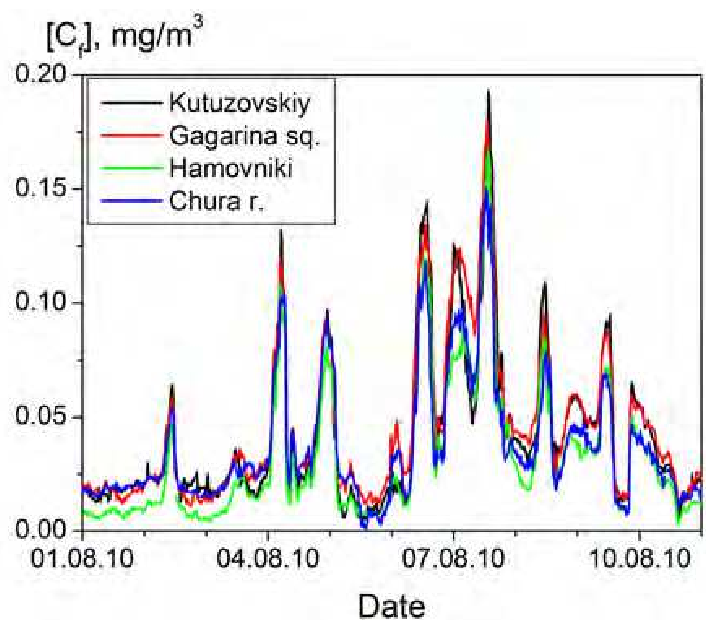

Fig. 11. Temporal variations of the formaldehyde concentration in the smoky atmosphere.

Year	Station	$\bar{C}$	σ	γ	**A**	E
		mg/m³				
2010 Smoke	Kutuzovskiy pr.	0.042	0.034	0.81	1.60	2.39
	Gagarina sq.	0.044	0.033	0.75	1.48	1.74
	Hamovniki	0.032	0.028	0.73	1.59	2.19
	Chura river	0.038	0.028	0.73	1.58	2.29
2009	Kutuzovskiy pr.	0.0104	0.0079	0.76	1.83	5.11
	Gagarina sq.	0.0143	0.0094	0.66	-0.36	0.19
	Hamovniki	0.0042	0.0030	0.72	0.23	-0.02
	Chura river	0.0106	0.0088	0.82	2.34	9.90

Table 20. Statistical characteristics of the formaldehyde concentrations (2009 and 2010-smoke)

7.2 Urban boundary layer

Extremely large concentrations of carbon monoxide occurred in the boundary layer also. Statistical characteristics of the carbon monoxide concentration variations at heights 2 m, 130 m, 248 m and 348 m are presented in Table 21. The average concentration of carbon monoxide at height of 348 m for less than at the smaller heights.

Statistical characteristics of the nitrogen dioxide concentration variations have been calculated (Table 22). The average profile of the nitrogen dioxide concentration in the smoky atmosphere is similar to the annual average profile. Thus the nitrogen dioxide concentration variations don't associate with the smoke screening of the urban atmosphere.

Height, м	$\bar{C}$	σ	γ	A	E
	mg/m³				
2	3.93	3.90	0.99	1.38	1.42
130	4.27	4.21	0.99	1.22	0.59
248	4.20	3.78	0.90	1.35	1.72
348	1.50	3.14	2.10	3.24	10.7

Table 21. Statistical characteristics of the carbon monoxide (CO) concentration (Ostankino, smoke).

Height, м	$\bar{C}$	σ	γ	A	E
	mg/m³				
2	0.034	0.028	0.84	2.15	11.3
130	0.049	0.029	0.58	0.81	0.07
248	0.025	0.024	0.97	2.20	7.04
348	0.014	0.011	o.77	2.25	7.340

Table 22. Statistical characteristics of the nitrogen dioxide (NO_2) concentration (Ostankino, smoke).

7.3 Aerosol mass concentration

In the smoky atmosphere of Moscow the extreme large aerosol mass concentrations PM10 have been observed (Table 23). Temporal variations of PM10 in the smoky atmosphere are depicted in Fig. 12.

The average mass concentrations in the smoke screening periods were 10 – 15 times greater than the annual average mass concentrations. Statistical parameters A and E in the smoky atmosphere were markedly less than that in 2009.

Station	$\bar{C}$	σ	C_{max}	γ	A	E
	mg/m³					
Kozhuhovo	0.345	0.314	1.68	0.91	1.26	1.25
Mar'inskiy park	0.317	0.303	1.72	0.96	1.40	1.50
Zelenograd	0.288	0.258	1.08	0.90	0.91	- 0.18
MSU	0.280	0.290	1.15	1.03	1.02	- 0.10

Table 23. Statistical characteristics of the aerosol mass concentration PM10 (2010, smoke)

8. Air pollution, adverse weather conditions and pollution health

Sufficiency elevated temperatures took place in July – August 2010 over European part of Russia. The temperature measurement data at Mosecomonitoring stations in the smoke screening period are presented in Fig. 13. "The urban heat island" over Moscow (Spiridonovka st., Ostankino) at the night time is clearly pronounced against a background (Zvenigorod station). The intensity of the temperature inversion reached 10 ºC in the lower200 m thick layer. Wind velocity in the lower layer of the atmosphere was moderate

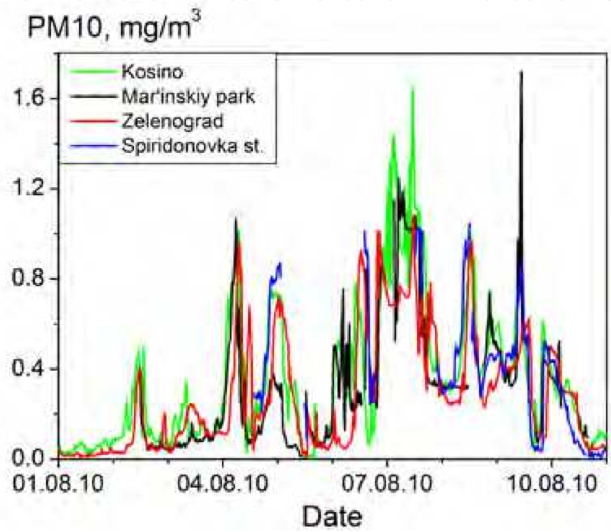

Fig. 12. Temporal variations of PM10 in the smoky atmosphere.

(Kallistratova, 2010). Meteorological conditions in July – August 2010 made for accumulation of the air pollution and containment of the smoke in the urban boundary layer. The joint action of the high temperature and the heavy air pollution impact negatively on the pollution health (Grechko et., 2010). In this period the premature mortality in central Russia has been grown (Revich, 2010).

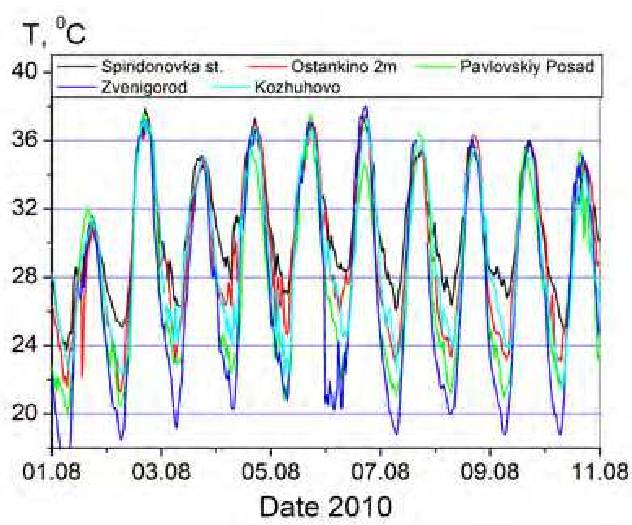

Fig. 13. Air temperature in the atmospheric surface layer at Mosecomonitoring stations (smoke screening period).

9. Conclusion

In this chapter the air pollution monitoring data in the Moscow region have been partly examined. The temporal variation of the gaseous species concentrations were analyzed including the diurnal and annual cycle of abovementioned concentrations. Statistical characteristic of the concentration variations for carbon monoxide, nitrogen oxides, ozone, methane and non – methane hydrocarbons has been calculated.

The aerosol mass concentration variations in Moscow region are discussed. The air pollution investigation results in the urban boundary layer are presented. The gaseous species and aerosol variability in smoky atmosphere is analyzed. It is shown that the aerosol mass concentration and carbon monoxide concentration in the smoke screening period were extremely large. The adverse weather conditions and the heavy air pollution influence on the population health are briefly discussed. It should be noted that the uncontrolled instrumental errors were possible in the smoky atmosphere.

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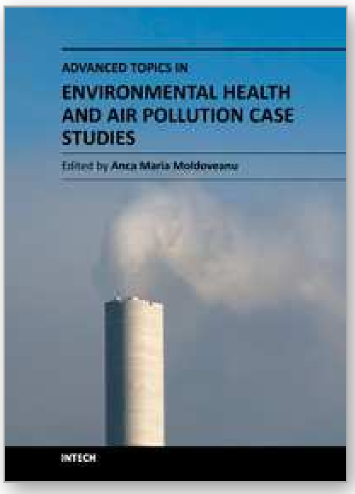

Advanced Topics in Environmental Health and Air Pollution Case Studies
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The book describes the effects of air pollutants, from the indoor and outdoor spaces, on the human physiology. Air pollutants can influence inflammation biomarkers, can influence the pathogenesis of chronic cough, can influence reactive oxygen species (ROS) and can induce autonomic nervous system interactions that modulate cardiac oxidative stress and cardiac electrophysiological changes, can participate in the onset and exacerbation of upper respiratory and cardio-vascular diseases, can lead to the exacerbation of asthma and allergic diseases. The book also presents how the urban environment can influence and modify the impact of various pollutants on human health.